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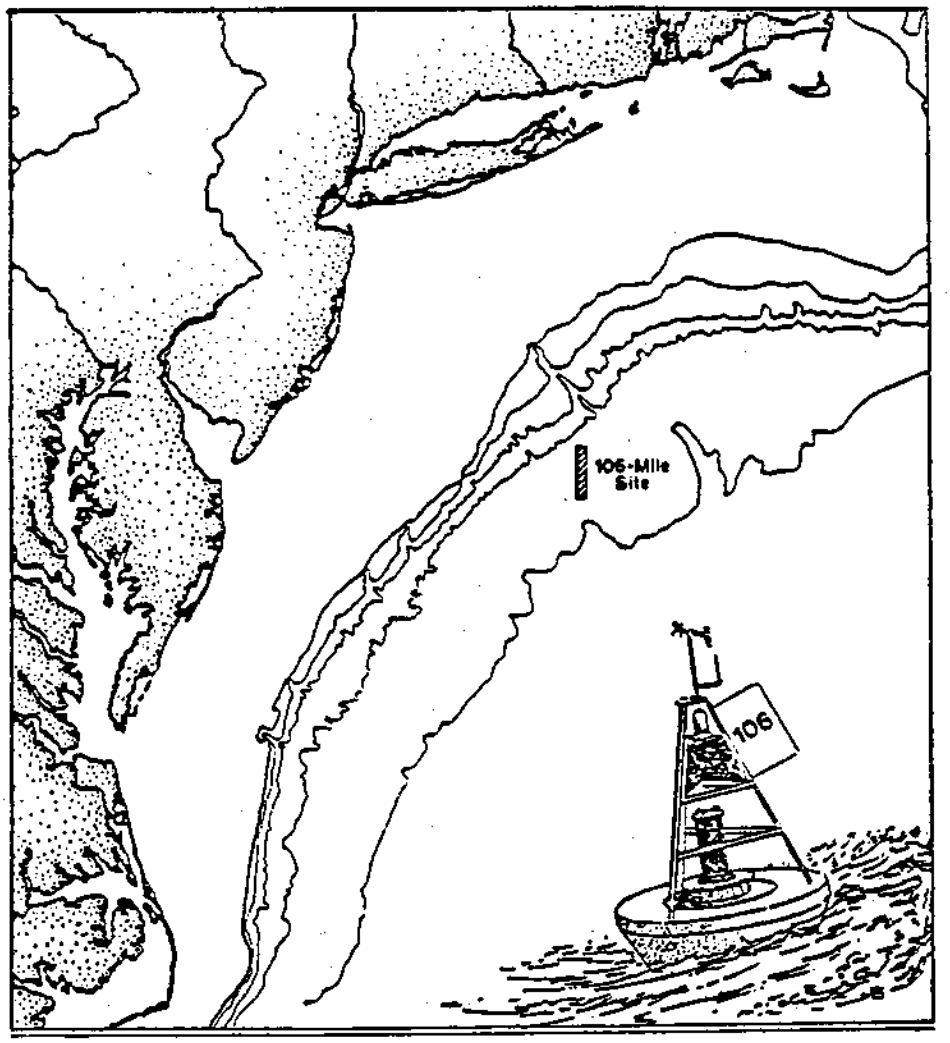

FINAL
REVISION TO INITIAL REPORT

RESULTS OF STUDIES CONDUCTED IN THE VICINITY OF 106-MILE DEEPWATER MUNICIPAL SLUDGE SITE

May 3, 1988

U.S. ENVIRONMENTAL PROTECTION AGENCY
Region II
New York, New York
and
Office of Marine and Estuarine Protection
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1. INTRODUCTION

The United States Environmental Protection Agency (EPA), under the Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA, PL 92-532), is responsible for regulating disposal of wastes, including sewage sludges, in ocean waters. Under MPRSA, EPA has published ocean dumping regulations (40 CFR Parts 92-532), which require EPA to develop and maintain monitoring programs for designated ocean disposal sites.

EPA has developed a monitoring plan (EPA , 1992a) for the 106-Mile Deepwater Municipal Sludge Site (106-Mile Site), located beyond the continental shelf off the New York/New Jersey coast. The objective of the monitoring program is to ensure that regulatory requirements are met. Data generated through the monitoring program will be used by EPA to make decisions about site redesignation or dedesignation; continuation, termination, or modification of permits; and continuation, termination, or modification of the monitoring program itself. The plan for implementing the monitoring program (EPA , 1992a) is summarized in Figure 1.

The monitoring strategy focuses on two areas of concern: assessment of compliance with permit conditions and assessment of potential impacts of sludge disposal on resources or other aspects of the marine environment. The approach used to address assessment of permit compliance and potential impacts uses a series of monitoring tiers. Each tier represents a series of null hypotheses, or questions, to be tested through monitoring activities. The tiered approach organizes the null hypotheses into a hierarchy, whereby data collected in each tier form the basis for the design and extent of monitoring activities in the next tier. Such an approach ensures that only information needed for making decisions will be obtained (Zeller and Wastler, 1987).

The purpose of this report, which is an updated revision of a previous report (EPA , 1986), is to review studies conducted in the vicinity of the 106-Mile Site. Those study results that pertain to or can be used to test the null hypotheses directed at the assessment of potential impacts (Tiers 2, 3, 4) will be summarized. Some of the information provided by the studies reviewed for this report can be used to establish baseline conditions within the vicinity of the site. Although not used in the

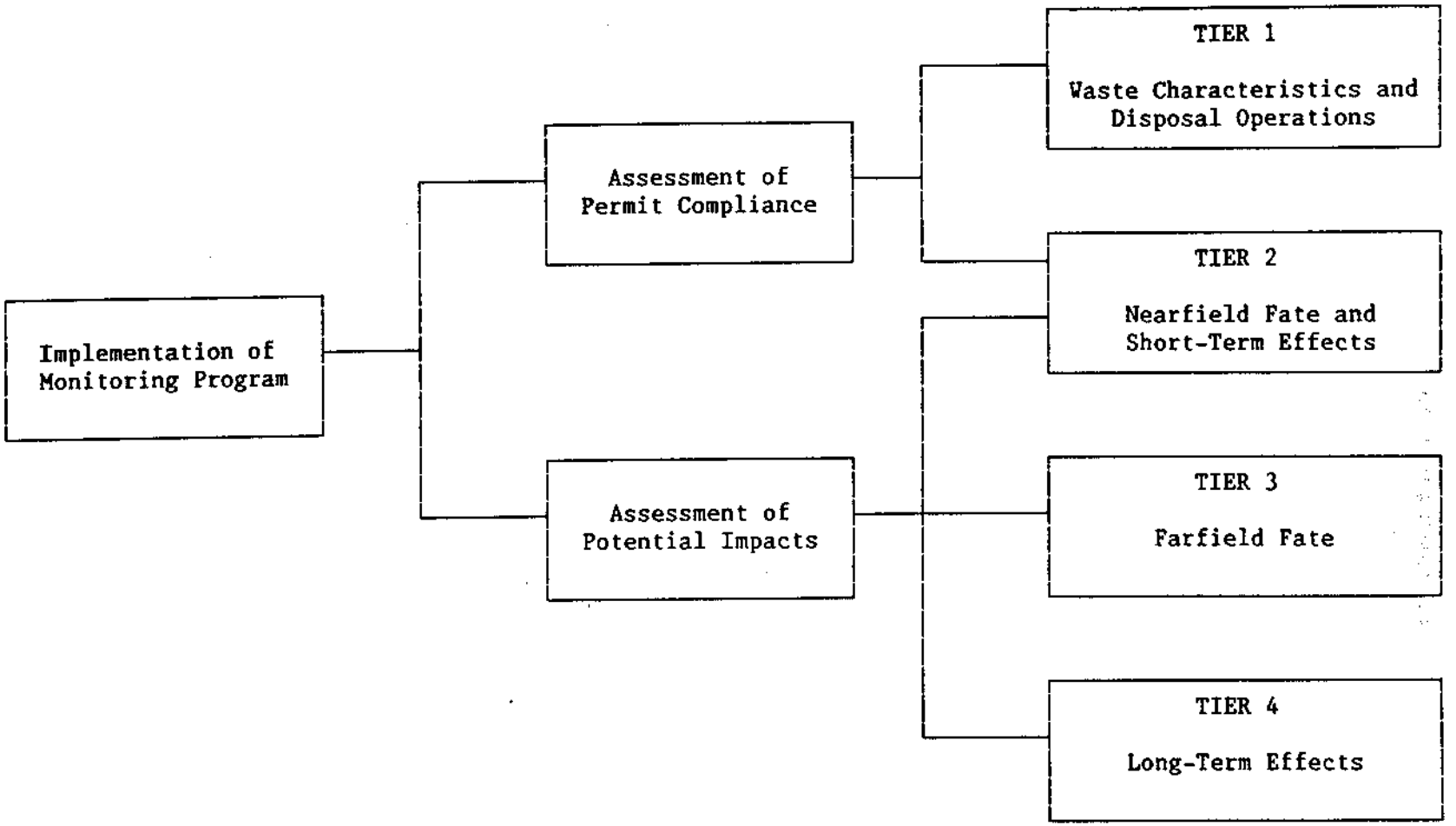

FIGURE 1. IMPLEMENTATION OF THE 106-MILE SITE MONITORING PROGRAM INVOLVES A TIERED APPROACH TO ADDRESS ASSESSMENT OF PERMIT COMPLIANCE AND POTENTIAL IMPACTS.

assessment of permit compliance, baseline conditions provide a frame of reference against which to compare the results of monitoring activities directed at the assessment of potential impacts (Tiers 2, 3, and 4).

The objectives of the monitoring tiers that address assessment of potential impacts are founded in the ocean dumping regulations, which specify the impact categories listed in Table 1. The monitoring plan (EPA , 1992a) describes the regulatory basis for the monitoring program and how the site and sludge characteristics have been used to predict potential impacts (Table 1) for each impact category resulting from sludge disposal. The predicted potential impacts have, in turn, been used to formulate the null hypotheses that have been organized into tiers (Figure 1) for testing through monitoring activities.

Because the emphasis in this report is on study results that provide information that can be used in the assessment of potential impacts, this report has been organized into sections corresponding to the monitoring tiers associated with assessment of potential impacts. Brief summaries of the studies reviewed for this report are presented in Section 2.

Section 3 lists the null hypotheses associated with Tier 2 (Nearfield Fate and Short-Term Effects), Tier 3 (Farfield Fate), and Tier 4 (Long-Term Effects) of the monitoring program. In addition to the null hypotheses, Section 3 includes the scientific issues relevant to each hypothesis, or the type of information needed to test each null hypothesis.

Summaries of study results are included in Section 4. Only those results that relate directly to the scientific issues of the null hypotheses are discussed. Because the null hypotheses contain issues that fall into three general scientific areas, Section 4 is organized into subsections for physical oceanography, marine chemistry, and marine biology.

TABLE 1. IMPACT CATEGORIES IDENTIFIED IN OCEAN DUMPING REGULATIONS AND PREDICTIONS FOR POTENTIAL IMPACTS OF SLUDGE DUMPING AT THE 106-MILE SITE.

Impact Categories	Predicted Potential Impacts
Impingement of sludge onto shorelines	P-1: Sewage sludges dumped at the 106-Mile Site will probably not impact any shoreline in detectable quantities.
Movement of sludge into marine sanctuaries or shellfishery or fishery areas	P-2: Marine sanctuaries and shellfishery areas will probably not be impacted by shoreward movements of sludge.
	P-3: Sewage sludge may be transported to the continental slope and shelf where fishery activities exist.
Effects of sludge on commercial fisheries	P-4: The impact of sludge dumping on commercial fisheries, expressed as direct decrease in fish stocks or decrease in eggs or larvae, will probably not be detected, and the use of any area for fishing will not be reduced.
Accumulation of sludge constituents in biota	P-5: Bioaccumulation of low levels of contaminants associated with sewage sludge from the 106-Mile Site will occur, from time to time, at the site or directly adjacent to the site, by migrating fishes or invertebrates, but may be difficult to distinguish from other potential sources.
	P-6: Bioaccumulation of low levels of contaminants by resident continental shelf/slope fishes or invertebrates may occur, depending on direction and extent of transport of sludge to these areas, but may be difficult to distinguish from bioaccumulation from other potential sources.
Progressive changes in water quality	P-7: Sewage sludge movement and transport beyond the site boundaries may result in significant impact on the water quality beyond the site.
	P-8: Sludge constituents may be found in significant quantities within the site at all times and may persist beyond 4 hours after disposal. Chronic effects on marine biota are possible.
	P-9: Though certain sludge constituents may be detectable well outside the site, their levels are not expected to have significant effects on marine biota.

TABLE 1. (continued)

Impact Categories	Predicted Potential Impacts
Progressive changes in sediment composition	P-10: Sludge particles may settle outside the disposal site boundaries. However, this settling will occur over a very large and as yet undefined area. The resultant changes in sediment composition, the destruction of habitat, and/or the accumulation of sludge constituents in surficial sediments will probably be nil to minimal.
Impacts on pollution-sensitive species	P-11: The disposal of sewage sludge probably will not cause long-term impacts on pollution-sensitive species or life-cycle stages in the water column or the sediments of the 106-Mile Site region. Effects may be detectable, but local and short-lived.
	P-12: The sea-surface microlayer in the disposal site and in an undefined area adjacent to the site, as well as the sensitive life stages of marine biota within may be affected by the surface-active components and nonpolar pollutant compounds present in sludges.
Impacts on endangered species	P-13: Endangered species of mammals or reptiles will probably not be impacted by sewage sludge disposal at the 106-Mile Site.
Progressive changes in biological communities	P-14: Due to nutrient enrichment in the upper water column, there may be a localized increase in primary productivity related to individual sewage plumes.
	P-15: There will probably be no long-term or large-scale impact on the plankton community as a result of sludge disposal at the 106-Mile Site.
	P-16: Because of the expected absence of sewage sludge particles in the demersal or benthic environment, no effects on the benthic or demersal community structures are likely.

2. SUMMARY OF STUDIES

Much information on physical characteristics and baseline chemical and biological conditions at the 106-Mile Site is available from studies conducted during the past decade. This information was used to develop the framework of the 106-Mile Site monitoring plan. It also represents a valuable resource that can be used to test the various hypotheses of the monitoring plan. The purpose of the initial version of this report, the Studies Document, (EPA , 1986) was to summarize the pertinent results of these major studies, but because the final project results were not available at that time, the Studies Document presented only an overview of individual project objectives and a summary of the field measurements. This report presents an update of the scientific results from the major studies that were identified in the initial Studies Document. Some additional studies have also been reviewed for this report because they provide information that is relevant to the issues at the 106-Mile Site.

In this section, the sampling design and scientific objectives of each of the reviewed studies are briefly summarized, with supporting information provided in Table 2. Each study has been numbered to facilitate simple reference in the text; locations of measurements for each study are shown in Figure 2. Table 3 summarizes important types of data obtained from each study. The data topics included in Table 3 have been specifically selected because they correspond to scientific issues raised by the null hypotheses, which are discussed in Section 3.

Study 1: Mid-Atlantic Slope and Rise Physical Oceanography Study (MASAR). This study, funded by the U.S. Department of the Interior (DOI), Minerals Management Service (MMS), was conducted by Science Applications International Corporation (SAIC) between September 1983 and September 1986. The study area (see Figure 2) was bounded by the shelf break to the west, the outer continental rise area to the east, 36°N to the south, and 40°N to the north. Current measurements, hydrographic measurements, and remote sensing data were used to evaluate potential impacts of petroleum exploration on the continental shelf, slope, and rise. The program was designed with the following objectives:

TABLE 2. BACKGROUND SUMMARY OF STUDIES CONDUCTED WITHIN THE VICINITY OF THE 106-MILE SITE.

Study	Sponsor	Prime Contractor	Date of Measurement
1. Mid-Atlantic Slope and Rise Physical Oceanography Study (MASAR)	DOI, MMS	SAIC	9/83 - 9/86
2. Shelf Edge Exchange Processes Program (SEEP)	DOE	BNL, L-DGO, WHOI, Yale	1982 - 1992
3A. Study of Biological Processes on the U.S. Mid-Atlantic Slope and Rise	DOI, MMS	Battelle	3/84 - 7/86
3B. Analysis of Trace Metals in Bottom Sediments on the U.S. Mid-Atlantic Slope and Rise	DOI, MMS	USGS	3/84 - 7/86
4A. Study of Biological Processes on the U.S. North Atlantic Slope and Rise	DOI, MMS	Battelle	11/84 - 4/87
4B. Analysis of Trace Metals in Bottm Sediments on the U.S. North Atlantic Slope and Rise	DOI, MMS	USGS	11/84 - 4/87
5. Four Studies of Baseline Conditions at the 106-Mile Site	EPA	5A. JRB 5B. Battelle 5C. Battelle 5D. Battelle	5A. 7-8/84 5B. 8/85 5C. 2/86 5D. 8-9/86
6. Study of Baseline Conditions at the North Atlantic Incineration Site	EPA	Battelle	11/85
7. Current Meter Measurements at the 106-Mile Site in Support of Municipal Waste Disposal	EPA	Battelle, SAIC	9/86 - 4/87
8. Analysis of Circulation Characteristics in the Vicinity of Deepwater Dumpsite 106	NOAA	EG&G	1968 - 1981

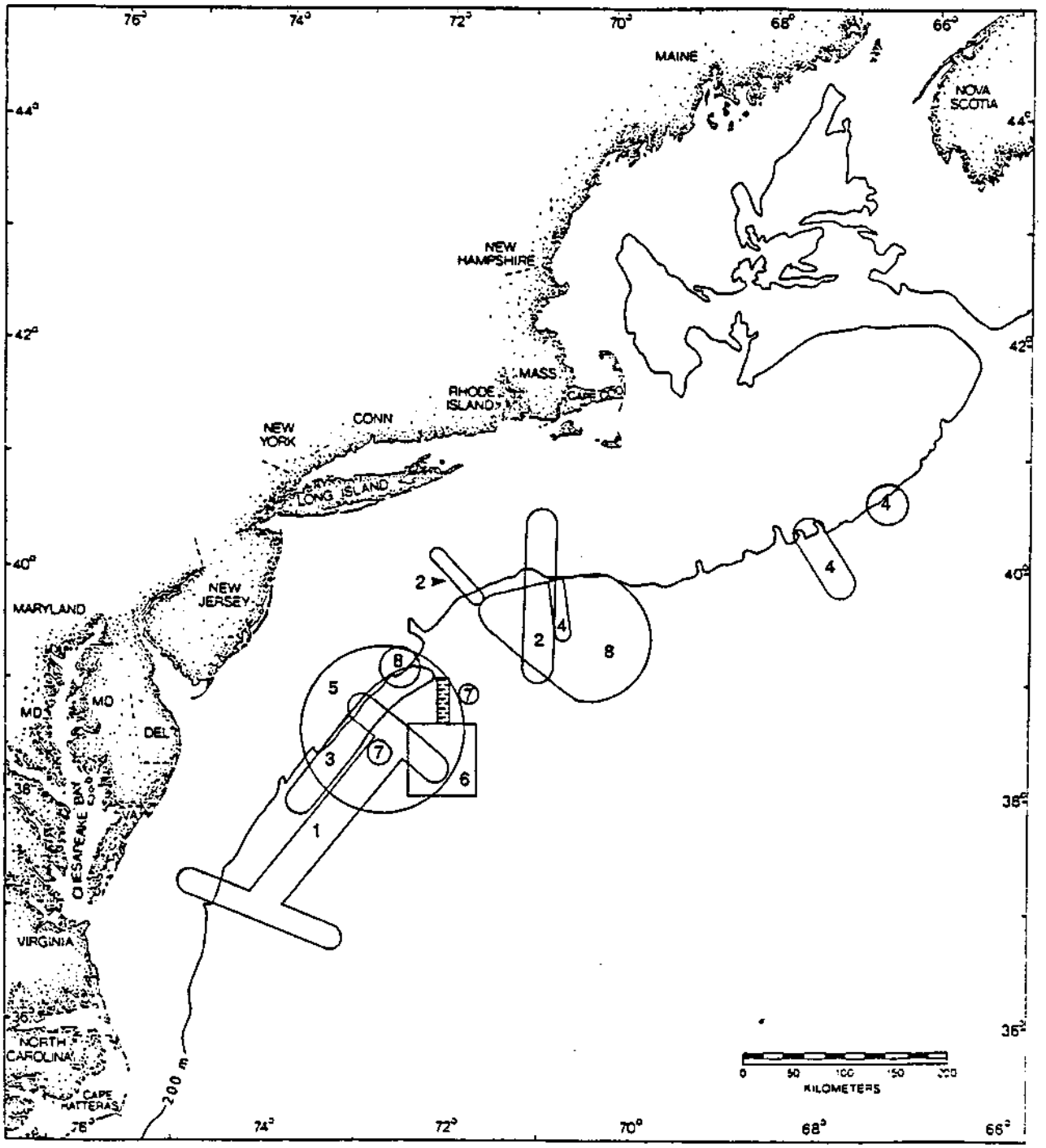

FIGURE 2. AREAL COVERAGE OF STUDIES CONDUCTED IN THE VICINITY OF THE 106-MILE SITE (SHADED AREA). STUDIES ARE IDENTIFIED BY NUMBER IN TABLE 2.

TABLE 3. SUMMARY OF THE TECHNICAL OBJECTIVES OF STUDIES CONDUCTED IN THE VICINITY OF THE 106-MILE SITE.

	Studies												
Objectives	1	2	3A	3B	4A	4B	5A	5B	5C	5D	6	7	8
Physical Oceanography													
Pycnocline Depth	x	x											
Currents	x	x										x	x
Particulates		x						x	x	x			
Marine Chemistry													
Metals			x	x	x	x	x		x	x			
Organics			x		x		x	x	x	x	x		
Dissolved Oxygen	x		x		x				x	x	x		
pH Levels									x	x	x		
Bioaccumulation			x		x						x		
Marine Biology													
Plankton Communities		x							x	x	x		
Endangered Species			x		x			x	x	x	x		
Benthic Communities			x		x								

- Determine general seasonal ocean circulation features.
- Quantify and describe ocean circulation processes that produce variability.
- Determine the degree to which continental slope and rise circulation features influence the physical oceanography of the adjacent Mid-Atlantic continental shelf.

Results of MASAR have been presented in a final program report (Science Applications International Corporation, 1987). Further analysis of the MASAR results with a model of the circulation in the slope water region has been presented by Csanady and Hamilton (1988).

Study 2: Shelf Edge Exchange Processes Program (SEEP). This program, funded by the U.S. Department of Energy, is an ongoing, multidisciplinary study conducted by Brookhaven National Laboratory (BNL), Lamont-Doherty Geological Observatory (L-DGO), Woods Hole Oceanographic Institution (WHOI), and Yale University. The program is designed as a multiphase study along the U.S. east coast from south of Nantucket Shoals to Cape Hatteras. The first phase (SEEP-I) consisted of a 1-year (1983-1984) physical, chemical, and biological measurement program across the outer continental shelf and upper slope south of New England (see Figure 2). Although each component of this multidisciplinary program has specific scientific objectives, the primary theme of the study is to define the processes that govern the distribution and fate of "energy-related pollutants" that might be introduced into the marine environment of the coastal United States. (Department of Energy, 1982). Measurements were specifically directed at resolving the fate of fine-grained particles from the continental shelf.

Scientific results of SEEP-I will be presented in a series of articles to appear in a special issue of Continental Shelf Research during the next few months. To facilitate review of the SEEP-I results prior to publication, the editor of Continental Shelf Research kindly made draft copies of selected articles available to Battelle.

SEEP-II, a companion monitoring program to SEEP-I, is being conducted in

the middle-Atlantic region (37° to 38°N), but these results will not be available for at least 2 years.

Study 3A: Study of Biological Processes on the U.S. Mid-Atlantic Slope and Rise; Study 3B: Analysis of Trace Metals in Bottom Sediments in Support of Deepwater Biological Processes Studies on the U.S. Mid-Atlantic Slope and Rise. Study 3A was conducted by Battelle, in conjunction with WHOI and L-DGO, for the U.S. DOI, MMS. The analysis of trace metals in sediments (Study 3B), performed by the U.S. Geological Survey (USGS), was supported under a separate interagency agreement. The studies were developed as a multidisciplinary monitoring program that focused on two deepwater exploratory drilling sites. Six sampling surveys were conducted between March 1984 and July 1986. The primary objectives of the monitoring program were the following:

- Characterize predrilling biological, geological, and chemical properties of benthic environments at 14 stations in the general vicinity of two exploratory drilling sites.
- Monitor potential changes in these properties with time, and to determine whether the changes are caused by drilling-related activities, or whether they are the result of other phenomena including natural temporal or spatial variation.
- Determine the distribution and fate of discharged drilling-related materials that have accumulated above background levels.
- Estimate recovery rates of deep-sea benthic communities potentially impacted by drilling-related activities.

Results of the monitoring program have been reported by Maciolek et al. (1987a) and Bothner et al. (1987a).

Study 4A: Study of Biological Processes on the U.S. North Atlantic Slope and Rise; Study 4B: Analysis of Trace Metals in Bottom Sediments in Support of Deepwater Biological Processes Studies on the U.S. North Atlantic Continental Slope and Rise. Studies 4A and 4B were developed as a companion program to the U.S. Mid-Atlantic Slope and Rise program (Studies 3A and 3B). The program was conducted by Battelle, in conjunction with WHOI and L-DGO. Analyses of metals in sediments by the USGS was supported under a separate interagency agreement. The multidisciplinary program, which included six

seasonal surveys between November 1984 and April 1987, had the following objectives:

- Characterize predrilling biological, geological, and chemical properties of benthic environments at a limited number of stations within areas of potential oil and gas development on the North Atlantic Slope and Rise.
- Monitor potential changes in those properties with time to determine the extent of natural temporal and spatial variation.
- Determine the background distribution of materials (such as trace metals and hydrocarbons) that may accumulate at elevated levels due to future drilling operations.

Results of these studies have been presented by Maciolek et al. (1987b) and Bothner et al. (1987b).

Study 5: Studies of Baseline Conditions at the 106-Mile Site. Study 5 actually refers to a series of four baseline surveys of the 106-Mile Site funded by EPA. The July/August 1984 survey (Study 5A) was conducted for EPA by JRB Associates; the August 1985 (Study 5B), February 1986 (Study 5C), and August/September 1986 (Study 5D) surveys were conducted for EPA by Battelle. Although the four surveys were conducted as separate studies, they all shared a common objective: to obtain information concerning baseline conditions at the 106-Mile Site. Results for each individual study have been presented in several reports (EPA , 1986; EPA , 1987a; EPA , 1988a).

Study 6: Study of Baseline Conditions at the North Atlantic Incineration Site. This EPA-funded study was conducted by Battelle in November 1985 as part of the ocean incineration program. The primary objectives of the study were to field-test sampling equipment and analytical methods for use during the monitoring of a research burn and to collect baseline data for water, air, and biota at the site. Results of the analysis of samples collected during the study have been reported by EPA (1987b).

Study 7: Current Meter Measurements at the 106-Mile Site in Support of Municipal Waste Disposal. This EPA-funded study was conducted by SAIC under

subcontract to Battelle. From September 1986 to April 1987, two current meter moorings were deployed on the 2500-m isobath northeast and southwest of the 106-Mile Site (Figure 2) . The moorings were designed to monitor the current and temperature structure of the upper layers of the ocean in the vicinity of the 106-Mile Site. The primary objective of the study was to assess the effects of various current regimes on sludge disposal. Results of the study have been reported by EPA (1992

Study 8: Analysis of Circulation Characteristics in the Vicinity of Deepwater Dumpsite 106. This study was performed by EG&G for the National Oceanic and Atmospheric Administration (NOAA). The scope of the study consisted of a review and analysis of more than 300 months of current meter data collected between 1968 and 1981. The primary objective was to describe the long-term mean circulation patterns in the continental slope region along the U.S. east coast. Investigators have reported on the general pattern of slope circulation based on monthly averaged data (National Oceanic and Atmospheric Administration, 1985).

3. HYPOTHESES WITHIN TIERS OF MONITORING PROGRAM

This section presents the null hypotheses associated with the monitoring program tiers introduced in Section 1. Because this report focuses on studies that may provide baseline information to be used in the assessment of potential impacts of sludge disposal, this section addresses only those null hypotheses within the following monitoring tiers:

- Tier 2: Nearfield Fate and Short-Term Effects
- Tier 3: Farfield Fate
- Tier 4: Long-Term Effects

The null hypotheses within Tier 1 (Waste Characteristics and Disposal Operations), which are related to assessment of permit compliance, are not addressable by any of the studies under consideration. Thus, the Tier 1 null hypotheses are not discussed in this report.

In addition to presenting null hypotheses, this section lists types of measurements or information that must be obtained in order to test each hypothesis. For example, H_o6, which is stated in Section 3.1, concerns the settling of sludge particles in relation to the pycnocline. In order to test H_o6, information is needed about the depth of the pycnocline, the settling rates of sludge particles, the background levels of particles in the vicinity of the 106-Mile Site, and regional current characteristics. Thus, the types of measurements relevant to H_o6 are pycnocline depth, sludge settling rates, and background particulate levels. Identifying the information relevant to each null hypothesis will facilitate the relation of study results to the data objectives of the monitoring program, as reflected in the null hypotheses.

3.1 TIER 2: NEARFIELD FATE AND SHORT-TERM EFFECTS

Nearfield fate and short-term effects monitoring addresses issues of both permit compliance and impact assessment. Nearfield fate determination addresses the horizontal and vertical behavior and movement of sludge within and immediately adjacent to the site. Short-term effects are defined as

those occurring within 24 hours. Knowing the behavior and movement of sludge immediately following disposal is necessary to test assumptions, regarding dispersion and dilution, that are used in permit-issuance decisions. Knowing the short-term effects of sludge disposal is necessary to test the assumption that permit compliance is sufficiently protective of the marine environment. The Tier 2 null hypotheses are as follows:

NEARFIELD FATE

H_o6: **Sludge particles do not settle in significant quantities to the seasonal pycnocline (50 m) in the summer or to the 50-m depth at any time, within the site boundaries or in the area adjacent to the site.**
Relevant information:
- Pycnocline depth
- Sludge settling rates
- Background particulate levels
- Currents

H_o7: **The concentration of sludge constituents within the site does not exceed the limiting permissible concentration (LPC) or water quality criteria (WQC) 4 hours after disposal and is not detectable in the site 1 day after disposal.**
Relevant information:
- Metals concentrations within the site
- Concentrations of organic compounds within the site

H_o8: **The concentration of sludge constituents at the site boundary or in the area adjacent to the site does not exceed the LPC or WQC at any time and is not detectable 1 day after disposal.**
Relevant information:
- Metals concentrations outside the site
- Concentrations of organic compounds outside the site

H_o9: **The disposal of sludge does not cause a significant depletion in the dissolved oxygen content of the water column nor a significant change in the pH of the seawater in the area.**
Relevant information:
- Oxygen concentrations in the area
- pH levels in the area

SHORT-TERM EFFECTS

H_o10: **No significant biological effects in the water column are measurable within the site within 1 day after disposal.**

Relevant information:
Biological conditions within the site

H_o11: No increase in primary productivity or any changes in planktonic biomass or species composition will occur.
Relevant information:
Primary productivity
Planktonic biomass

H_o12: No evidence of short-term bioaccumulation of sludge constituents by commercially important species found at or adjacent to the site or in important prey species found at or adjacent to the site will be found within 1 day after disposal.
Relevant information:
Commercially important species
Important prey species
Bioaccumulation of metals
Bioaccumulation of organic compounds

H_o13: Sludge constituents do not accumulate in the surface microlayer in the vicinity of the site.
Relevant information:
Surface microlayer concentrations of sludge constituents

3.2 TIER 3: FARFIELD FATE

Before any estimation of long-term effects resulting from sludge disposal at the 106-Mile Site can be made, it is necessary to determine where the sludge goes, the area of the seafloor that may be influenced by sludge particles, and the cumulative concentrations that may be expected in the water column and sediments after many years of disposal. The null hypotheses within Tier 3 relate to where the sludge goes over the long term.

Null hypotheses concerning farfield fate address impact issues that pertain to potential movement toward and subsequent impact to shorelines (predicted potential impact P-1, refer to Table 1), to marine sanctuaries and fisheries (P-2), and to the continental shelf/slope (P-3). The Tier 3 null hypotheses also address information necessary in deciding whether studies should be conducted under Tier 4 to determine whether there is a potential for long-term impacts from sludge disposal, and if so, where those studies should be conducted. The Tier 3 null hypotheses are as follows:

H_o14: Sludge constituents do not settle beneath the pycnocline outside the disposal site.
Relevant information:
- Pycnocline depth outside the site
- Sludge settling rates
- Currents
- Metals concentrations outside the site
- Concentrations of organic compounds outside the site

H_o15: Ocean currents do not transport sludge to any adjacent shoreline, beach, marine sanctuary, fishery, or shellfishery.
Relevant information:
- Onshore currents via the slope circulation, warm-core eddies, or other processes.

H_o16: Sludge recirculation through the site is not significant.
Relevant information:
- The hypothesized slope sea gyre or recirculation via warm-core eddies that revisit the site

H_o17: Sludge particles do not settle to the sea floor in the vicinity of the site or in the region predicted as a possible settling region based on laboratory settling measurements and current trajectory analysis.
Relevant information:
- Sludge settling rates
- Currents
- Metals concentrations in sediments
- Concentrations of organic compounds in sediments

3.3 TIER 4: LONG-TERM EFFECTS

The objective of Tier 4 is to assess whether there are long-term impacts of sludge disposal at the 106-Mile Site. Long-term effects may occur within or outside the site. An example of long-term effects within the site would be a progressive decline in water quality, although such an effect is not predicted. Long-term effects outside the site, such as bioaccumulation of sludge constituents, would only be expected if sludge is regularly transported in a given direction (determined through studies of farfield fate).

Because the null hypotheses within Tier 4 are related to long-term effects, the studies results summarized in Section 4 are not sufficient to

test the Tier 4 hypotheses. However, baseline data provided by some of the studies may be used as a reference against which to compare data obtained through monitoring activities. The Tier 4 null hypotheses are as follows:

H_o18: Sludge constituents have no significant long-term effect on the distribution of endangered species in the vicinity of the site.
Relevant information:
- Endangered species distributions

H_o19: Sludge constituents do not accumulate in the tissues of commercially important species resident in shelf/slope areas adjacent to the site.
Relevant information:
- Commercially important species
- Bioaccumulation of sludge constituents

H_o20: Benthic community structure does not change significantly due to sludge disposal.
Relevant information:
- Benthic community structure

H_o21: Sludge disposal has no effect on the sensitive eggs and larval stages of indigenous animals.
Relevant information:
- Indigenous animals (i.e., important commercial, important prey, endangered, and benthic species)
- Effects of sludge constituents on eggs and larvae of indigenous animals

H_o22: Sludge disposal has no measurable long-term impact on offshore plankton communities.
Relevant information:
- Plankton communities

H_o23: Pathogen levels will not increase in the water column or in the biota.
Relevant information:
- Pathogen levels

4. STUDY RESULTS APPLICABLE TO MONITORING PROGRAM

This section focuses on those study results that are applicable to the null hypotheses that form the framework of the monitoring program. Table 4 lists the data issues associated with each hypothesis (refer to Section 3). The information needed to address the null hypotheses used in the assessment of potential impacts can be divided into the following general categories:

- Physical oceanography
- Marine chemistry
- Marine biology

This section is organized according to the three general categories of relevant information, rather than by hypothesis, because many of the data issues are contained in several hypotheses (see Table 4). In this manner, results that may be applicable to several hypotheses may be related to the information common to those hypotheses, rather than repeated for each of the hypotheses.

4.1 PHYSICAL OCEANOGRAPHY

The null hypotheses directed at the assessment of nearfield (Tier 2) and farfield.(Tier 3) fate require, as input, information on the physical oceanographic processes and conditions at the 106-Mile Site and surrounding regions. Although there exist a myriad of processes that ultimately affect the dynamics of this region, only those that will have a significant effect upon the vertical and horizontal transport of sludge dumped at the site will be addressed in the present review of studies results. Table 4 illustrates that there are two scientific issues/processes within the category of physical oceanography that are expected to have a major effect on the behavior of sludge dumped at the 106-Mile Site:

- Pycnocline depth
- Currents

TABLE 4. DATA ISSUES CONTAINED IN THE NULL HYPOTHESES ASSOCIATED WITH THE ASSESSMENT OF POTENTIAL IMPACTS.

	Hypotheses																
Issues	6	7	8	9	10	11	12	13	14	15	16	17	18	19	21	22	23
Physical Oceanography																	
Pycnocline Depth	x								x		x						
Currents	x								x	x	x	x					
Marine Chemistry																	
Metals		x	x				x	x				x		x			
Organic Compounds		x	x				x	x				x		x			
Dissolved Oxygen				x													
pH Levels				x													
Marine Biology																	
Plankton Communities					x												x
Primary Productivity					x	x											
Planktonic Biomass					x	x											
Commercial Species					x		x						x			x	
Important Prey Species					x		x									x	
Endangered Species					x							x				x	
Benthic Communities					x									x		x	
Pathogens					x												x

Pycnocline depth is known to play a major role in the settling (vertical transport) of sludge, whereas, currents govern the dispersion and advection (horizontal transport) of sludge, both in the nearfield and the farfield. In the following subsections, a summary of recent (and site-specific) results is presented for each oceanographic process: pycnocline depth (subsection 4.1.1) and currents (subsection 4.1.2). Results are presented by individual study; synthesis of all study results for a specific process was beyond the scope of this review project. The individual results illustrate that much is known about the physical processes that will ultimately affect the transport of sludge dumped at the 106-Mile Site. It is also important to note that these processes will not be affected by the sludge, in contrast to local chemical and biological characteristics which may be significantly altered by sludge disposal. The knowledge of physical processes that has been gained from the past studies is, thus, directly applicable to the conditions that will be encountered during sludge disposal, whereas chemical and biological measurements from past surveys represent only baseline data from which to make short-term (Tier 2 and 3) and long-term (Tier 4) assessments of the effects of sludge disposal at the site.

4.1.1 Pycnocline Depth

The term pycnocline refers to a layer in the water column where vertical gradients of density are strong relative to the remainder of the water column. With regard to ocean dumping of seawage sludge, the pycnocline is an important factor affecting sludge behavior because it represents a potential barrier to vertical mixing and settling of sludge particles. In extreme cases where the pycnolcine is very intense, particles may be prohibited from settling through the pycnocline and accumulation will be significant at this depth. In practice, however, particle settling is difficult to predict as it is highly dependent upon particle characteristics (e.g., size, density) pycnocline intensity, and seawater viscosity.

The depth of the pycnocline off the U.S. east coast varies according to three principal factors: (1) location, (2) season, and (3) resident water mass and/or oceanographic feature. At any given site, there is a smoothly varying seasonal cycle to pycnocline depth; this cycle is a direct result of

solar radiation. In summer, a near-surface seasonal pycnocline separates the warm surface waters from the underlying, relatively cool, dense water that comprised the upper water column during the prior winter and spring. As the overlying atmosphere cools in autumn, and increased winds and waves cause intense vertical mixing in the near-surface layers, the seasonal pycnocline is eroded from the surface and a relatively cool, surface mixed layer is formed. The depth of this winter mixed layer varies greatly from year to year, in relation to the number and intensity of the storms passing over the region. This winter mixed layer often extends to depths of 100 m or greater, such that the base of the mixed layer coincides with the top of the permanent pycnocline. Thus, the depth of the pycnocline in summer refers to the depth of the seasonal pycnocline, whereas in winter when the seasonal (summer) pycnocline is absent, pycnocline depth refers to the depth of the permanent pycnocline.

MASAR and SEEP (Studies 1 and 2)

To determine the seasonal variability of pycnocline depth in a particular region such as the 106-Mile Site, it is necessary to analyze a large number of vertical density (temperature and salinity) profiles from each season, and preferably, from a number of years to address interannual variability. A large number of hydrographic profiles were made across the continental shelf and slope during the MASAR and SEEP programs (see Figure 2), but because pycnocline depth was not one of the principal analysis topics, the density profile results are not presented in a form that allows simple interpretation of seasonal variability in pycnocline depth.

The MASAR hydrographic program consisted of eight cruises, with one cruise per season in both 1984 and 1985. These data would yield a fair representation of the seasonal cycle within 2 consecutive years, but two observations from each season do not represent a good statistical sample of pycnocline depth for all years. Similarly, the relatively small number of hydrographic surveys made during SEEP would not yield a good statistical representation of seasonal and interannual variations in pycnocline depth because of the limited sampling program.

Analyses of Historic Data

An accurate, statistical determination of pycnocline depth and its seasonal variability at the 106-Mile Site can only be derived from a numerical analysis of many years of hydrographic profile results, such as the data archives maintained by the National Oceanographic Data Center (NODC). For example, a less extensive yet informative analysis of historical hydrographic data from the 106-Mile Site has been presented by Warsh (1975) in NOAA Dumpsite Evaluation Report 75-1. Warsh has presented monthly averaged temperature and salinity profiles from which seasonal variations in pycnocline depth can easily be interpreted. Figure 3 presents the seasonal cycle of pycnocline depth as derived from the results presented by Warsh (1975). In this figure, the permanent pycnocline exhibits considerable depth variability ranging from a maximum of 200 m in April to a minimum of 100 m throughout the remainder of the year. The upper boundary of the seasonal (summer) pycnocline is, in contrast, very shallow (10 to 30 m) and present only from May through October. This figure illustrates that although the permanent pycnocline exists throughout the year, the seasonal pycnocline will be the limiting factor in the initial mixing and vertical penetration of sludge dumped at the 106-Mile Site during summer. A more comprehensive numerical analysis of historic NODC hydrographic data will be required to refine these statistical estimates of pycnocline depth and its seasonal variability. Spatial variations in pycnocline depth can also be investigated in conjunction with the temporal analyses of pycnocline depth.

Nearfield Monitoring Studies

In addition to seasonal variations, pycnocline depths can also be affected by the passage of anomalous water masses and/or oceanographic features. At the 106-Mile Site, warm-core eddies of Gulf Stream origin and displaced parcels of shelf water can have major impacts on the vertical profile of density in the upper water column. For example, under sustained northerly wind conditions, shelf water has been observed as far offshore as the 106-Mile Site, and when this occurs, large vertical density gradients can arise at the interface between the shelf and slope water masses. Such an

event was observed during the Winter 1988 nearfield monitoring survey of the 106-Mile Site (EPA , 1988b): a 40-m thick layer of relatively fresh shelf water lay above the resident slope water creating a temporary pycnocline that was much shallower than the permanent pycnocline. This "shelfwater" pycnocline would greatly reduce the vertical penetration of sludge dumped at the 106-Mile Site during winter conditions. This hypothetical (yet previously observed) case is superimposed on the seasonal cycle of pycnocline depth presented in Figure 3.

Similar temporary (3- to 15-day), nonseasonal variations in pycnocline depth can also be caused by the passage of warm-core eddies. The waters within these eddies are less dense than typical slope waters, and consequently, vertical density profiles on the edge of these eddies may exhibit near-surface pycnoclines that are much shallower than ambient pycnoclines. This occurrence is especially true during winter when the surface temperatures within the eddies are much greater than surface temperatures of the ambient slope water. In summer, surface temperatures within the eddies are similar to those of the surrounding waters, and pycnocline depths may not be affected as much as during winter. Nevertheless, warm-core eddies must be viewed as an important physical mechanism for large, short-term changes in pycnocline depth at the 106-Mile Site. Additional data analyses will be required to quantify their potential effects during all seasons.

4.1.2 Currents

Information on currents at the 106-Mile Site is required for two primary purposes: (1) to determine the rates at which sludge is transported out of the site after discharge (nearfield fate studies), and (2) to predict the pathways and rates of farfield transport. The likelihood of sludge recirculation through the site is also a major topic of interest.

Results from a variety of recent current measurement programs and numerical modeling studies have greatly increased the knowledge of currents and circulation along the U.S. east coast and in the vicinity of the 106-Mile Site. These results are summarized below according to individual research programs; however, it is informative to first provide a brief introduction to

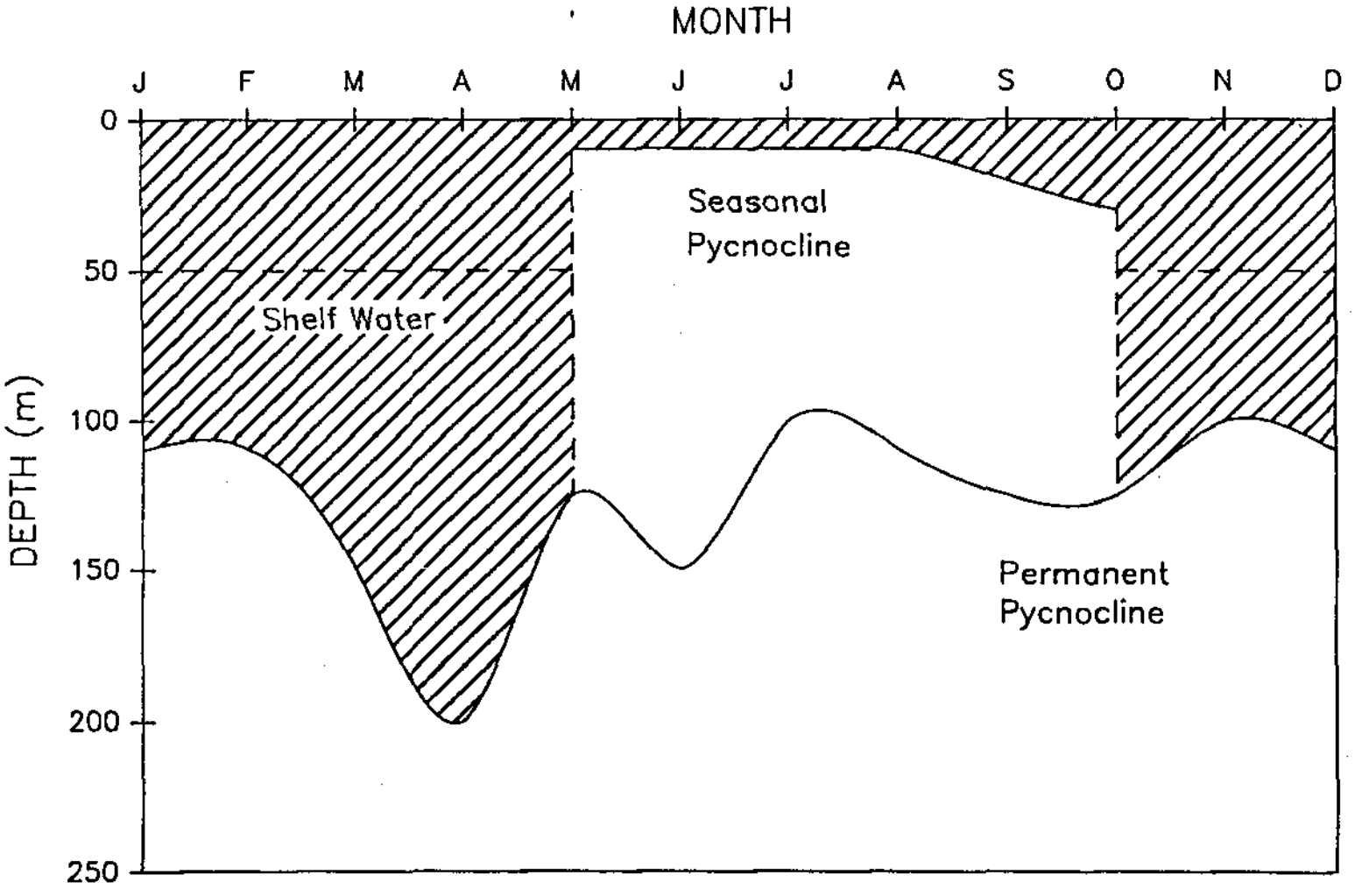

FIGURE 3. SCHEMATIC REPRESENTATION OF SEASONAL VARIATIONS IN PYCNOCLINE DEPTH AT THE 106-MILE SITE. THREE CASES ARE ILLUSTRATED: THE PERMANENT PYCNOCLINE; THE SEASONAL PYCNOCLINE; AND A PYCNOCLINE CAUSED BY A SURFACE LAYER OF SHELF WATER.

the four major oceanographic processes that govern the currents of the region: the slopewater circulation, warm-core Gulf Stream eddies, mesoscale and submesoscale eddies that frequent the shelf/slope front, and events where shelf water reaches as far offshore as the 106-Mile Site. Specific issues concerning sludge transport for each of these current regimes include the following:

Slopewater Circulation

- Do the weak, southwestward currents within the slope water represent the "normal" current pattern such that farfield transport of sludge will almost always be directed toward the southwest?
- During the slopewater current regime, is sludge transported onto the continental shelf or toward major fisheries or sanctuaries?
- Can sludge be recirculated through the site by the hypothesized slopewater gyre?
- Will sludge contained within the slope water ultimately be injected into the Gulf Stream and transported northeastward away from the site?

Warm-Core Gulf Stream Eddies

- Can eddies transport sludge from the 106-Mile Site onto the continental shelf or into important fishery areas?
- Do strong eddy-induced currents increase nearfield sludge dilution?
- Will sludge dumped within an eddy remain trapped inside the eddy for a period of months?
- Do individual eddies revisit the 106-Mile Site and thus represent a mechanism for sludge recirculation through the site?

Mesoscale Eddies at the Shelf/Slope Front

- Do the mesoscale and submesoscale eddies that are found at the edge of the continental shelf represent an important mechanism for the transport of slope water through the shelf/slope front and onto the continental shelf?

Shelfwater Events

- Does the shelfwater/slopewater front move offshore as far as the 106-Mile Site?
- Will sludge discharged within a shelfwater event at the site be transported back onto the shelf?

Project results that help to answer these technical questions/issues are summarized below.

MASAR (Study 1)

Using the extensive hydrographic and moored current meter data sets generated by the MASAR program, and historic data from previous measurement programs in the region, Csanady and Hamilton (1988) have developed a conceptual model of the circulation within the slope sea, the region that lies between the Gulf Stream and the continental shelf (Figure 4). The prominent western component of this slope sea gyre is expected to vary in size and intensity, as a result of with changes in the large-scale wind forcing, the location of the Gulf Stream, and variations in the inflow of Labrador Sea water from the northeast. The 106-Mile Site is situated in the strongest part of the southwestward-flowing inshore arm of the anticlockwise (cyclonic) slope sea gyre. This result is consistent with the predominantly southwestward (~10 cm/s) mean currents that were observed near the 106-Mile Site during MASAR and other studies.

This conceptualized model of the circulation within the slope sea (Figure 4) is intended to represent the "mean" circulation in the absence of eddies spawned from the Gulf Stream and the shelf/slope front. The MASAR results suggest that this elliptical circulation is present on the slope roughly 85 percent of the time; eddies and other short-lived, small-scale processes are present at the site for the remainder of the time (roughly 15% on an annual basis). Currents associated with these "transient" (2- to 20-day) events can be 5 to 15 times greater than the typical southwestward slopewater flow, and current directions can vary by 180° over periods of a day or less during these events.

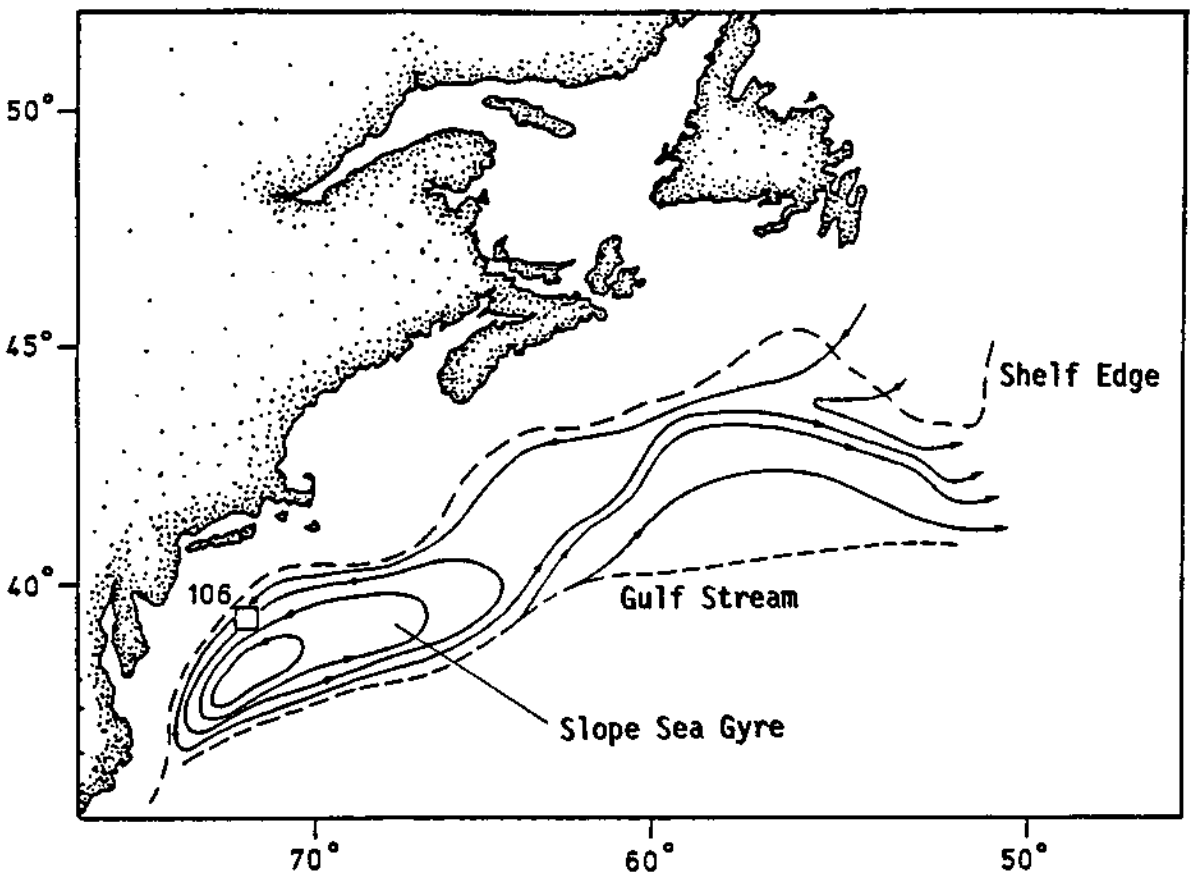

FIGURE 4. CONCEPTUAL MODEL OF THE CIRCULATION IN THE SLOPE WATER REGION, AS PRESENTED BY CSANADY AND HAMILTON (1988).

These and other significant MASAR results that pertain to the currents and circulation at the 106-Mile Site are summarized below:

- In the absence of eddies and other transient features, currents at the site are primarily directed toward the southwest, with mean speeds that vary from 20 cm/s above 250 m to about 9 cm/s near 1000 m. This southwestward flow is consistent with existing theories of a cyclonic slope sea gyre whose inshore, southwestward flow coincides with the location of the 106-Mile Site.

- The strength of the slope sea gyre may have a seasonal dependence, with strong flow during winter and apparent stagnation during summer.

- The position of the Gulf Stream has an indirect, yet significant effect on the strength of the southwestward flow of slope water in the vicinity of the 106-Mile Site. When the axis of the Gulf Stream is displaced northward of its mean position, the slope sea gyre is constricted and southwestward currents at the site are intensified.

- Analyses of satellite thermal imagery suggest that water from the 106-Mile Site often travels southwestward, to a point near Cape Hatteras, where the slope water is constricted between the continental shelf and the Gulf Stream. At this location, slope water is believed to be advected toward the northeast along the northern side of the Gulf Stream, thus creating the southern arm of the cyclonic slope sea gyre.

- During the passage of warm-core Gulf Stream eddies, current speeds above 100 m can exceed 1 m/s, whereas maximum speeds at 1000 m are on the order of 30 cm/s. Current directions during the passage of eddies may vary greatly over a period of a few days.

- In the absence of large perturbations such as warm-core eddies, currents may be spatially coherent over horizontal scales of 100 to 200 km. During eddy events, currents lack spatial coherence beyond a few tens of kilometers.

- Submesoscale (30 to 50 km diameter) eddies are a common feature at the edge of the continental shelf. These eddies represent a significant mechanism for driving intrusions of slope water onto the shelf. Cross-frontal transfer of water (and potentially, sludge) is more likely during summer than winter, on account of seasonal variations in horizontal temperature and density gradients.

SEEP (Study 2)

The primary focus of phase 1 of the multidisciplinary Shelf Edge Exchange Program (SEEP-I) was to determine the fate of fine-grained particles in the continental shelf water column south of New England. The dynamics in the adjacent slopewater region was also a topic of investigation because of its supposed effect upon the sedimentation of particles onto the slope. Commensurate with these objectives, the majority of the SEEP-I moored current measurements were made on the outer shelf and upper slope region south of New England (near 71°W). Although SEEP-I generated a relatively large number of year-long records of currents, temperature, and turbidity throughout the water column inshore of the 500-m isobath, only one current record was obtained from the upper 250 m of the water column offshore of the 500-m isobath. Thus, with regard to the currents and circulation at the 106-Mile Site, the SEEP-I results are useful for resolving the dynamics at the shelf/slope front, but they contribute little to our knowledge of the current variability further offshore, in the vicinity of the 106-Mile Site.

The SEEP-I results that pertain to currents and exchange of water masses at the shelf/slope front are summarized below. These results have been presented in the following articles: Walsh et al. (1988); Houghton et al. (1988); Aikman et al. (1988); and Flagg (1988).

- At the shelf break south of New England, the SEEP-I results confirmed a net offshore flow in the surface layer (0 to 40 m) as well as in the bottom (~30 m thick) Ekman layer. Onshore flow was observed at mid-depth.

- Wind-induced upwelling within the slope sea is weak, such that only 20 percent of the slope water eventually enters the shelfwater region.

- Mean currents are westward (alongshore) on both the shelf and slope, but current speeds are significantly greater on the shelf than further offshore.

- There is a clear minimum in kinetic energy (current speed) on the mid-slope compared to sites further inshore and offshore. This mimimum would support the hypothesis of increased particle settling on the mid-slope and eventual down-slope transport of particles within the bottom nepheloid layer.

- Horizontal exchange of water (and temperature) through the shelf/slope front exhibits a strong seasonal dependence. In winter, the front is characterized by a sharp temperature gradient that fluctuates over distances of 10-20 km on time scales of 4 to 20 days. Cross-frontal exchange exhibits high short-term variance in winter, but zero net transfer. In summer, shelf and slope waters become connected along isopycnal surfaces, with the result of significant onshore mass and heat flux across the shelf/slope front.

- Internal waves generated at the shelf/slope front can produce a significant bottom mixed layer that can result in significant cross-frontal exchange of shelf and slope waters, and suspended particulate matter.

- During the passage of a warm-core Gulf Stream eddy along the slope, the eddy-induced onshore heat flux was large, and 3 times greater than the offshore flux, but its effect was not detected on the continental shelf.

EPA Current Measurements at the 106-Mile Site (Study 7)

Under contract to EPA, Battelle and SAIC conducted a 7-month moored current measurement program to monitor the current structure in the upper 1000 m of the water column in the vicinity of the 106-Mile Site. The measurements were intended to provide more site-specific current information, with increased vertical resolution, than that resulting from the MASAR program. Current meters were situated at depths of 50, 100, 250, and 1000 m on each of the two moorings bracketing the 106-Mile Site. Although only two current records were obtained from depths above 250 m during this measurement program, a number of interesting results arose from this 7-month (September through April) program. The results pertinent to the issue of sludge disposal at the 106-Mile Site are summarized below:

- During the 7-month deployment period, currents were highly variable due to a wide variety of physical processes including a large warm-core Gulf Stream eddy, two smaller warm eddies, cool filaments of shelf water extruded from the shelf by the eddies, warm parcels of water extending from Gulf Stream meanders, moderate southwestward flow of the slope sea gyre, and strong inertial currents associated with intense winter storms.

- Some of these processes had not been detected during previous

current measurement programs in the vicinity of the 106-Mile Site (e.g., MASAR) because of the lack of sampling above 100 m.

- For the duration of the 7-month records the mean current speed was 6.5 cm/s directed toward the southwest (along the isobaths); the mean current was remarkably uniform with depths between 50 and 1000 m.

- During the passage of the warm-core Gulf Stream eddy, mean currents in the upper 250 m of the water column were on the order of 15 cm/s and directed toward the northeast. The mean current speed at 1000 m during this event was 5 cm/s toward the southwest.

- Southwestward currents during the EPA measurement program were roughly half the speed of currents observed during the MASAR program. The intensification of the slope sea gyre during MASAR was a result of a prolonged northward displacement of the Gulf Stream.

- Intense current oscillations having amplitudes of 30 cm/s were observed during the passage of the warm-core Gulf Stream eddy. These intense current "jet" structures have been previously observed at the outer edges of eddies (Joyce and Stalcup, 1984).

- Spectral analysis of the current records illustrates that warm-core eddies are responsible for the major portion of current variability, at periods greater than 10 days. Inertial currents dominate the high frequency current variability, with lesser contribution from the M2 semidiurnal tidal constituent.

- Along-shore currents at the two mooring sites were not coherent over the 75-km mooring spacing, presumably because of the current variability imparted by the eddies. For low frequencies, onshore currents were highly coherent yet 180° out of phase at the two mooring sites.

Analysis of Historical Current Records (Study 8)

This study represents the most comprehensive numerical analysis of the large number of moored current measurements that were made along the continental slope region of the U.S. east coast (between 69° and 73°W) during the period from 1968 through 1981. This Eulerian database consisted of 150 separate records constituting roughly 300 months of current data. A major result of this extensive analysis of historic current data is that, to a first approximation, it is reasonable to use the long-term statistics gathered from a wide array of station locations along the U.S. east coast to

describe the basic features of the slope circulation in the vicinity of the 106-Mile Site. On this basis, the following results can be applied to the current regime at the 106-Mile Site:

- Monthly averaged current data reveal an isobath-parallel flow toward the west or southwest in the slopewater region. This mean current system extends throughout the water column and across the width of the slope water region from the shelf break to at least 150 km offshore.

- Monthly mean currents are strongest above 200 m, with speeds ranging up to 50 cm/s and averages in excess of 10 cm/s. Variations in current speeds and directions are also greatest near the surface.

- Warm-core Gulf Stream eddies represent the major source of current variability within the slopewater region. Current speeds in excess of 1 m/s may persist for periods of several days during these events.

- Although current speeds decrease consistently with depth over the water column, there does not appear to be a consistent pattern to the depth dependence of current direction. This variability of the vertical current structure is significant because it implies that shear dispersion is an effective mechanism for the dispersion of sludge dumped at the 106-Mile Site.

- Mean residence time of water within an area corresponding to the 106-Mile Site is expected to be less than a few days. Periods of weak currents (e.g., <5 cm/s) are observed on an infrequent basis (~10%) and generally do not persist for periods of more than 2 days.

- Periods of shoreward currents are infrequent, with an incidence of roughly 15 percent. The speed of these currents would be sufficient to carry sludge from the 106-Mile Site to the edge of the continental shelf within a period of several days.

- Short-term recirculation events, which would return sludge to the 106-Mile Site within periods of a few weeks or less, are rare.

- The long-term fate of sludge dumped at the 106-Mile Site appears to be entrainment by the Gulf Stream within a period of roughly 1 month, with little likelihood of subsequent large-scale recirculation to the slopewater region.

Drifter Trajectory Studies

Over the past 10 years, Dr. Thomas Rossby at the University of Rhode Island has conducted a variety of Lagrangian drifter studies to investigate the mid-depth circulation within the Gulf Stream and throughout the western North Atlantic. The initial studies used neutrally buoyant SOFAR (sound fixing and ranging) floats that transmitted low-frequency sound signals to allow tracking via submerged, coastal, acoustic receivers. Since 1984, Rossby has used RAFOS (the inverse of SOFAR) floats to further investigate the dynamics within the Gulf Stream. RAFOS floats listen to moored sound sources, which is opposite to SOFAR floats, which are transmitters. RAFOS floats also have the added advantage that they actively follow isopycnal (constant density) surfaces, which yields a better three-dimensional trajectory of water parcels.

Bower et al. (1986) have presented a summary of RAFOS data from the vicinity of the Gulf Stream which were compiled during 1984 and 1985. Figure 5 presents a "spaghetti diagram" of float trajectories that were acquired from floats deployed in the Gulf Stream offshore Cape Hatteras (near 35°N). The majority of these trajectories followed the core of the Gulf Stream toward the northeast, but three floats exited the stream near 38°N, 72°W and entered the slope water near the 106-Mile Site. These floats moved northward until they reached the continental slope (~2000-m isobath in Figure 5), then began to move southwestward along the isobaths in agreement with typical slope water flow. Curiously, these floats turned southward to reenter the Gulf Stream about 2 weeks after having entered the slope water. Although these few trajectories do not provide a statistical representation of float trajectories in the vicinity of the 106-Mile Site, these results illustrate that sludge dumped at the 106-Mile Site may, on occasion, enter the Gulf Stream relatively soon after disposal. In this scenario, sludge would be transported rapidly toward the northeast with little possibility of recirculation through the site.

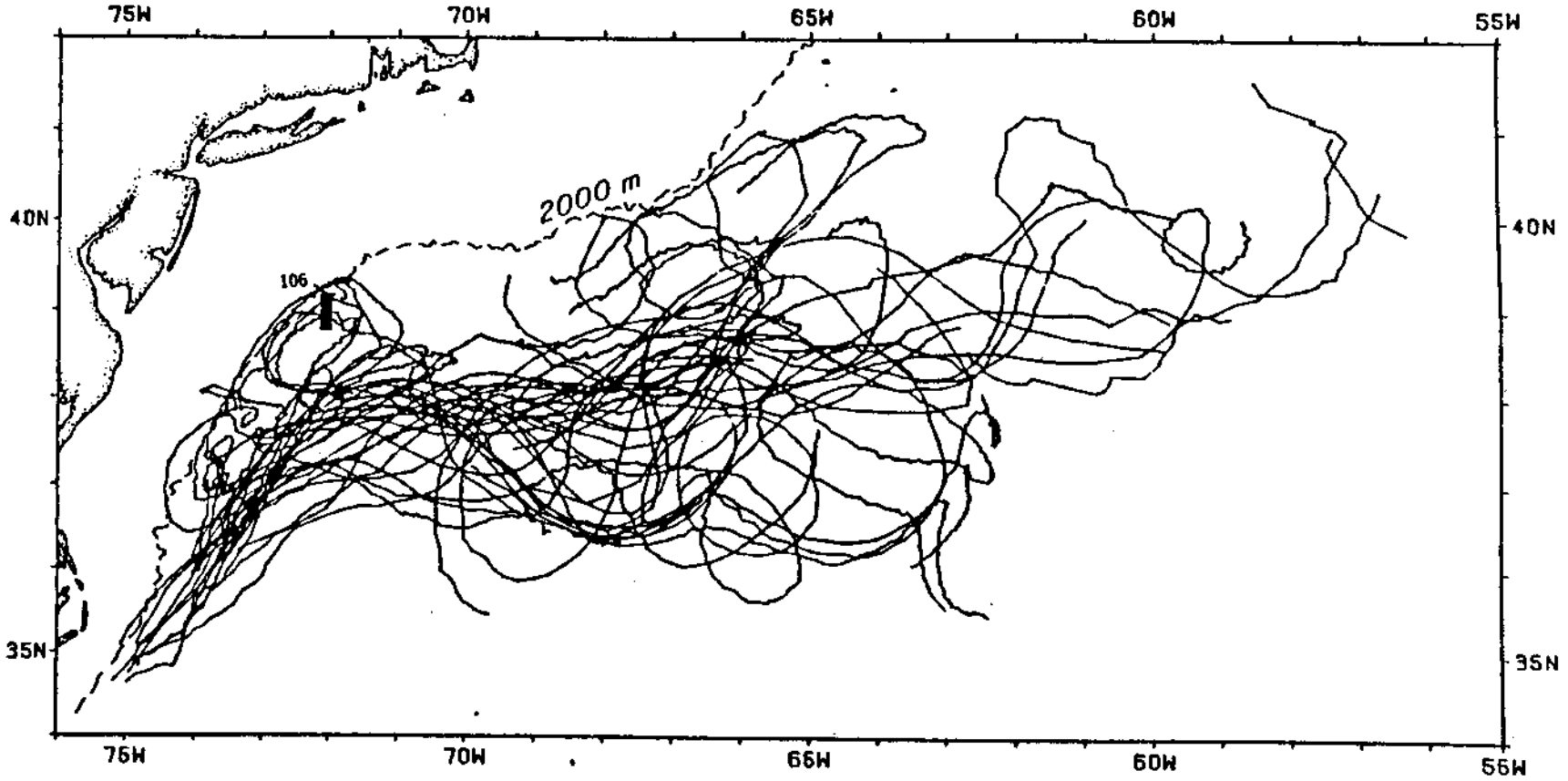

FIGURE 5. TRAJECTORIES OF SUBSURFACE DRIFTERS LAUNCHED IN THE GULF STREAM OFFSHORE NORTH CAROLINA (NEAR 35°N, 75°W), FROM BOWER, O'GARA AND ROSSBY (1985).

4.2 MARINE CHEMISTRY

The null hypotheses directed at the assessment of nearfield and farfield fate raise the following information issues that come under the general category of marine chemistry:

- Metals
- Organics
- Dissolved oxygen
- pH levels

Analyses for metals and organic compounds are an integral part of the 106-Mile Site monitoring plan. As implied by references to LPC and WQC in H_o7 and H_o8, bioaccumulation of sludge constituents in H_o12 and H_o19, settling of sludge particles to the sea floor in H_o17, and surface microlayer accumulation in H_o13, measurements of concentrations of dissolved metals and organic compounds are needed to determine the fate of sludge constituents. Dissolved oxygen concentrations and pH, referenced in H_o9, address impacts to the water column in the immediate vicinity of disposal activity.

Data available from the studies reviewed for this report are not sufficient to test the applicable null hypotheses. However, these studies, particularly the baseline surveys (Studies 5 and 6), provide important baseline data for comparison with the results of future monitoring activities.

Because none of the studies reviewed for this report specifically sampled the surface microlayer, there are no baseline data available to address the issue, raised in H_o20, of accumulation of sludge constituents in the surface microlayer.

The issue of bioaccumulation of sludge constituents in the tissues of commercially important/important prey species is raised in H_o12 and H_o18. Although bioaccumulation is monitored to provide an indication of change in biological conditions, the topic is included in this subsection because bioaccumulation studies involve chemical measurements. Although Studies 3A

and 4A included analyses of benthic faunal tissues, none of the studies specifically targeted tissue analyses of commercial and prey species. Thus, there are insufficient baseline data against which to compare the results of future chemical analyses of these species.

Because it is beyond the scope of this report to present the chemical data generated in the studies reviewed, this section will describe the types of data available (e.g., metals in sediments, surface water) and reference reports where data are presented. Wherever possible, this section will summarize study conclusions.

4.2.1 Metals

Analyses of metals were conducted in many of the studies reviewed for this report (Table 3). For purposes of obtaining baseline data for testing monitoring hypotheses, the matrices of interest are the surface microlayer (H_o13), the water column (H_o7 and H_o8), the tissues of commercially important and prey species (H_o12 and H_o19), and sediments (H_o17). Because none of the studies reviewed included microlayer sampling, data are not available for metals concentrations in this matrix.

Studies 3A and 4A

The studies of biological processes on the Mid- and North Atlantic slope and rise included analyses of metals in brittle stars (*Ophiomusium lymani*), sea urchins (*Echinus affinis*), and red crabs (*Geryon quinquidens*), which are fished commercially in some areas (Maciolek et al., 1987a; Maciolek et al., 1987b). The metals analyzed in the whole body tissue samples (Al, Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb, V, Zn, and Hg) were near detection limits with the exception of aluminum, iron, and zinc. The authors reported that the higher levels of aluminum, iron, and zinc may have been associated with ingested sediment.

Studies 3B and 4B

Studies 3B and 4B provide results from the analyses of trace metals in bottom sediments from the Mid- and North Atlantic slope and rise (Bothner et al., 1987a; Bothner et al., 1987b). Twelve metals (Al, Ba, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, V, and Zn) were analyzed in sediments collected over a 2-year period. Metal concentrations in samples from the Mid- and North Atlantic slope and rise were lower than those reported for world average shales, indicating no major contamination. In sediments from some stations adjacent to drilling rigs, barium, a major element in drilling mud, exhibited a small increase ($\leq$ 32 percent) in concentration over the study period . An enrichment of lead was detected in surface sediments relative to deeper sediments. This enrichment was presumed to result from the onshore combustion of leaded fuels.

Baseline Surveys (Studies 5A, 5C, 5D)

As part of the August 1984 survey of the 106-Mile Site (Study 5A), filtered seawater and seawater particulates were analyzed for silver, iron, lead, and zinc (EPA , 1987a). Only zinc was detected in the filtered seawater samples, although the accuracy of the results is questionable because of the high concentrations of zinc in the field blanks. Zinc and iron were the only metals detected in seawater particulates, with the Hudson Canyon station having higher metals concentrations than the other areas. Sediments were analyzed for iron, mercury, lead, and zinc; measurable concentrations were reported for all sediment samples.

The February 1986 survey to the 106-Mile Site (Study 5C) included analyses of metals in unfiltered seawater (i.e., including particulates) and in sediments (EPA , 1987a). For seawater samples, copper, lead, mercury, silver, and zinc were not detected above the field blank levels. Cadmium was only detected below the thermocline. Chromium concentrations were slightly higher in the slope water than on the shelf. Iron concentrations were significantly higher at the shelf station than at the shelf break or on the slope. Most trace metal concentrations were more than a thousand times lower than EPA's WQC for seawater. Sediments were analyzed for silver, cadmium,

chromium, copper, iron, mercury, lead, and zinc. Concentrations were generally lower than those reported from the 1984 survey for comparable metals. However, the authors suggested that the variability was most likely due to differences in analytical technique.

The August 1986 survey to the 106-Mile Site (Study 5D) included analyses of unfiltered seawater samples for silver, cadmium, chromium, copper, iron, lead, and zinc (EPA , 1986). Silver and lead were not detected in any of the samples. The reported concentrations for cadmium, chromium, iron, and zinc were higher than generally accepted values for the area. Copper concentrations were consistent with previously reported values.

In summary the studies reviewed herein provide some baseline data for concentrations of metals in the water column and in sediments. Because many metals were not found in samples above detection limits, additional data and lower detection limits are needed to establish actual baseline concentrations. The studies do not provide data on metals concentrations in the surface microlayer nor in the tissues of prey and commercially important species, with the exception of red crabs, indicating a need for baseline data of this type.

4.2.2 Organic Compounds

Analyses of organic compounds were performed in many of the studies in the vicinity of the 106-Mile Site (Table 3). As with metals, the matrices of interest for relating results to the null hypotheses are the surface microlayer (H_o13), the water column (H_o7 and H_o8), the tissues of commercially important and prey species (H_o12 and H_o19), and sediments (H_o17).

Studies 3A and 4A

Some sediments and tissues from the Mid- and North Atlantic slope and rise were analyzed for organic constituents as part of Studies 3A and 4A (Maciolek et al., 1987a; Maciolek et al., 1987b). Total hydrocarbon concentrations in sediments ranged between 2.9 and 27.1 µg/g dry weight at North Atlantic stations and between 2.9 and 52.9 µg/g dry weight at Mid-

Atlantic stations (see Figure 2). Concentrations of polynuclear aromatic hydrocarbons (PAH) in general covaried with total hydrocarbon concentrations, ranging between 10 and 364 ng/g dry weight at North Atlantic stations and between 66 and 1157 ng/g dry weight at Mid-Atlantic stations. The concentrations at the Mid-Atlantic stations appeared similar to, but higher than, concentrations found in earlier studies in the same geographic area. Sediments from both studies were also analyzed for total organic carbon, hydrogen, and nitrogen. In general, sediments from the Mid-Atlantic stations contained higher levels of organic carbon, hydrogen, and nitrogen.

Tissues of brittle stars (Ophiomusium lymani) and red crabs (Geryon quinquidens) from North Atlantic stations contained very low hydrocarbon concentrations. Total hydrocarbon concentrations in brittle stars ranged between 29.5 and 54.6 μg/g wet weight whereas concentrations in red crabs ranged between 5.5 and 11.8 μg/g wet weight. Hydrocarbon concentrations in brittle stars and sea urchins (Echinus affinis) from Mid-Atlantic stations ranged between 27.4 and 163.1 μg/g wet weight.

Baseline Surveys (Studies 5A, 5B, 5C, 5D, and 6)

Sediment samples were collected for analyses of organic compounds during the August 1984 (Study 5A) and August 1985 (Study 5B) surveys to the 106-Mile Site (EPA , 1987a). With the exception of 4,4'-DDT, which was detected in trace amounts along a southwest transect through the 106-Mile Site, no organic pollutants were detected in any sediments.

Filtered seawater and seawater particulates were collected for organics analyses during the February 1986 (Study 5C) survey to the 106-Mile Site (Battelle, 1987c). Samples were analyzed for PAH, polychlorinated biphenyls (PCB), pesticides, and coprostanol. With the exception of aldrin, a pesticide found in the slope samples, and coprostanol in the shelf sample, no pollutants of interest were found in seawater particulate samples. PCB were not detected in any of the samples in either the particulate or filtrate phase. Filtered seawater samples did contain some analytes in concentrations above method detection limits. Naphthalenes, phenanthrenes, and dibenzothiophenes were only found in shelf waters. A pesticide, α-BHC, was

found in both shelf and slope waters. Heptachlor and aldrin were also found in several samples.

Filtered seawater and seawater particulate samples were collected for organics analyses during the August 1986 (Study 5D) survey to the 106-Mile Site (EPA , 1992b). Filtered seawater samples were analyzed for PAH; particulate samples were analyzed for PCB, pesticides, and coprostanol. Seawater samples from all stations at both sampling depths (surface and subpycnocline) contained naphthalene and alkylated naphthalenes. The only other PAH detected, C_1-phenanthrene, was detected in some seawater samples. No PCB or coprostanol were detected in any particulate samples. Some pesticides (α-BHC, β-BHC, γ-BHC, δ-BHC, 4,4'-DDE, 4,4'-DDT, and heptachlor) were detected in some particulate samples.

The November 1985 (Study 6) baseline survey of the North Atlantic Incineration Site included sampling of filtered seawater and seawater particulates. Results were reported for analyses of PCB, PAH, pesticides, chlorobenzenes, polychlorinated dibenzo-p-dioxins (PCDD), and polychlorinated dibenzofurans (PCDF)(EPA , 1987b). In all cases but two, no PCDD nor PCDF were detected in seawater samples. Measurable PCB were detected in only one seawater sample. Chlorobenzenes were not detected in any seawater samples. Low levels of PAH were detected in seawater samples from all but one station; no PAH were detected in any particulate samples. Low levels of pesticides were detected in seawater and particulate samples from two out of the five stations sampled.

In summary the data generated in the studies reviewed herein provide much baseline data for organics in seawater, particulates, and sediments. The studies do not provide baseline data for the surface microlayer or, with the exception of red crabs, the tissues of commercially important and prey species.

4.2.3 Dissolved Oxygen and pH

The effects of sludge disposal on dissolved oxygen concentration and pH in the vicinity of disposal are issues raised in $H_0 9$. Because these parameters are expected to be routinely measured during all monitoring

activities, the value of historical results are limited. Dissolved oxygen concentrations have been reported for Studies 1, 3A, 4A, 5C, 5D, and 6. A typical range for reported dissolved oxygen concentrations is 7.0 - 7.8 mg/L (EPA , 1987b) in surface water and 4.9 - 6.6 mg/L (EPA , 1988a) at 250-m depths. Measurements of pH have been reported for Studies 5C, 5D, and 6. Typically, pH ranges between 7.8 and 8.3 (EPA , 1988a).

4.3 MARINE BIOLOGY

The null hypotheses directed at the assessment of short- and long-term effects (Tiers 2 and 4) focus on changes in biological conditions within and near the 106-Mile Site. The specific marine biological measurements dictated by the hypotheses are as follows:

- Plankton communities
- Primary productivity
- Planktonic biomass
- Commercially important species
- Important prey species
- Endangered species
- Benthic communities
- Pathogens

Because none of the studies reviewed in this report were specifically directed at monitoring short- or long-term effects of sludge disposal at the 106-Mile Site, none of the null hypotheses in Tiers 2 and 4 can be tested using available data. However, the data that are available provide a baseline against which future monitoring data can be compared.

4.3.1 Plankton Communities

The issue of the long-term effects of sludge disposal on plankton communities is raised in $H_0$22. Primary productivity and planktonic biomass, issues found in $H_0$11, are issues that are also related to plankton communities.

Baseline Surveys (Studies 5C, 5D, and 6)

The most recent baseline surveys (Studies 5C and 5D) of the 106-Mile Site and the baseline survey to the North Atlantic Incineration Site (Study 6) have included measurements of chlorophyll (as chlorophyll *a*), phaeophytin, and adenosine triphosphate (ATP). ATP is used as an indication of the biomass of live microorganisms, including bacteria, phytoplankton, and zooplankton; chlorophyll is used as an indication of the quantity of phytoplankton in seawater; and phaeophytin is a degradation product of chlorophyll. Whereas ATP and chlorophyll provide an indication of planktonic biomass and primary productivity, the ratio of chlorophyll to phaeophytin provides an indication of the health of the phytoplankton population. The ratio of chlorophyll to phaeophytin decreases in phytoplankton at depths below the euphotic zone or in areas of heavy zooplankton grazing. EPA (1987a, 1987b, 1988a) has reported results of these measurements at stations within and in the vicinity of the 106-Mile Site; normal chlorophyll/phaeophytin range between 1.4 and 1.7.

SEEP (Study 2)

As part of Study 2, Walsh et al. (1988b) conducted high-frequency sampling of the 1984 spring bloom within the Mid-Atlantic Bight. Data were obtained from moored fluorometers, transmissometers, thermistors, and current meters deployed south of Martha's Vineyard and Long Island; airborne sensors; and shipboard bottle and fluorescence-conductivity-temperature-depth (F/CTD) casts. Data were used to estimate the export of phytoplankton from the Mid-Atlantic during the 1984 spring bloom and to provide validation data for a simulation model (Walsh et al., 1988c). The results suggested a seaward

export of perhaps 0.20 mg chlorophyll m^{-3} day^{-1} at depths of 75-81 m during February to April 1984. This horizontal loss of algal carbon would represent 19-67 percent of the March-April 1984 primary production within the overlying euphotic zone. Estimates of the vertical flux of organic carbon suggested that approximately 50 percent of the carbon export at the shelf break might be derived from the adjacent overlying water column, with the rest derived from lateral injections of near-bottom particles originating on the inner shelf.

Although the data generated in Study 2 may be of limited value in testing the null hypotheses associated with plankton communities, the data generated from Studies 5C, 5D, and 6 provide important baseline information for comparing results of future monitoring at the 106-Mile Site.

4.3.2 Commercial, Prey, and Endangered Species

The issue of bioaccumulation of sludge constituents by important commercial or prey species is raised in H_o12 (short-term effects) and H_o18 (long-term effects). The long-term effect of sludge constituents on the distribution of endangered species is addressed in H_o17.

As indicated in Table 3, observations of cetaceans, marine turtles, and seabirds have been conducted by the Manomet Bird Observatory as part of several surveys to the 106-Mile Site and the North Atlantic Incineration Site (Battelle, 1984; EPA , 1987a; EPA , 1987b; EPA , 1988a). Cetaceans and marine turtles observed in the vicinity of the 106-Mile Site include sperm, minke, fin, pilot, and possibly sei whales; dolphins, grampus, and leatherback turtles. Several species of seabirds, which are not expected to be directly affected by sludge disposal, were also observed. It should be noted that not all of the species observed (e.g., pilot whales, dolphins, grampus) are on the endangered list. Endangered species distributions were also reported as part of the Northeast Monitoring Program (NOAA, 1983).

The National Oceanic and Atmospheric Administration (NOAA, 1983) has reported on the distribution of fish and fisheries in the vicinity of the 106-Mile Site. The survey, conducted as part of the Northeast Monitoring Program, includes commercially important and important prey species.

Because results of the Northeast Monitoring Program are not recent, this program was not selected as one of the primary programs (Table 3) reviewed for this report. More recent data on distributions of endangered species are available (Battelle, 1984; EPA , 1987a; EPA , 1987b; EPA , 1988a) and provide more relevant baseline data for comparison with future monitoring studies. None of the studies reviewed for this report specifically address distributions of important commercial or prey species.

4.3.3 Benthic Communities

The issue of long-term effects on benthic community structure is raised in H_O20. Comprehensive studies of benthic community structure along the Atlantic slope and rise in the vicinity of the 106-Mile Site have been conducted as part of Studies 3 and 4. A wealth of baseline data has been generated and reported by Maciolek et al. (1987a, 1987b).

Benthic Infauna

The diversity of benthic infaunal species was evaluated by Hurlbert rarefaction, species accumulation over increasing area, and Shannon-Wiener methods. For the Mid-Atlantic study (Maciolek et al., 1987a), diversity at the mid-slope (2020 - 2195m) stations (176 to 184 species per 1000 individuals) was greater than that at the remaining stations (144 to 171 species per 1000 individuals). A similar result was reported for the North Atlantic study (Maciolek et al, 1987b) where the mid-slope stations (1220 - 1350m) exhibited higher diversities than either shallower or deeper stations. Polychaetes comprised the majority of dominant species at all depth intervals within the Mid- and North Atlantic study areas. The top dominant at stations deeper than 2020 m was the spionid polychaete Aurospio dibranchiata. Infaunal communities at the shallower, mid-slope stations were dominated by the sipunculan Aspidosiphon zinni and the aplacophoran mollusc Prochaetoderma yongei. Water depth and sediment grain size were significant determinants of infaunal community structure. The diversity of the benthic infaunal community was stable over all sampling seasons. Wet, dry, and ash-free dry

weights were also reported for both the Mid-Atlantic and North Atlantic studies.

Benthic recolonization experiments were conducted as part of Studies 3A and 4A. In a significant result from the Mid-Atlantic study, the 6-month experiment conducted in 1985 showed recolonization by a different fauna than was observed over the same time period in 1984 (Maciolek et al., 1987a). Results from both studies suggested that recolonization of disturbed or defaunated sediments is very slow (on the order of years) in the deep sea relative to shallow coastal water depths (weeks to months).

Benthic epifaunal community structure was also examined as part of Studies 3A and 4A. The results of the Mid-Atlantic study indicated trends in epifaunal trophic structure and species composition which were related to a combination of depth and topography (Maciolek et al., 1987a). The highest density of total megafauna (5-6 individuals/m^2) was observed at depths between 1800 and 1900 m. Faunal density was lower (3-4 individuals/m^2) at depths between 1900 and 2350 m. Higher densities were also found on shallow ridges and in flat valleys than on steep slopes and in deep valleys. Similar densities of total megafauna were recorded for the western transect of the North Atlantic study at depths between 1800 and 2200 m (Maciolek et al., 1987b). Although filter feeders and deposit feeders were both dominant, their relative proportion shifted according to bottom topography. A higher proportion of filter feeders was found on ridges and in flat valleys; a higher proportion of deposit feeders was found on steep slopes and in deep valleys. No consistent seasonal or yearly differences in epifaunal community structure were reported for either study.

The data obtained as part of the studies of biological processes on the U.S. Mid- and North Atlantic slope and rise provide much recent baseline data on benthic communities in the vicinity of the 106-Mile Site. Although these data are not sufficient to test the relevant null hypothesis H_o20, they may be used to compare results of future monitoring studies.

4.3.4 Pathogens

None of the studies reviewed for this report included baseline information regarding pathogens in the vicinity of the 106-Mile Site. This lack of information will be addressed in future monitoring studies in order to test the related null hypothesis, H_o23.

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